Predicting Tropical Cyclone Formation and Structure Change

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LONG-TERM GOALS

The long-term goals are to create and deliver knowledge-based expert system modules that will allow the Joint Typhoon Warning Center (JTWC) forecasters to make more accurate and consistent forecasts of tropical cyclone formation and outer wind structure.

OBJECTIVES

A tropical cyclone formation expert system module has become necessary due to the Navy requirement for five-day track forecasts. A tropical cyclone may form and reach typhoon intensity in under five days, which may pose a threat to exercises and ship operations. Because dynamical model tropical cyclone structure and track guidance tends to be less accurate during the early stages of the tropical cyclone life cycle, the prime objective during this past year has been to identify the capability of numerical models to forecast tropical cyclone formation. This includes a geographic assessment of the potential for tropical cyclone formation, which implies that the distribution of tropical cyclone formation locations will reflect favorable synoptic-scale conditions.

APPROACH

The overall project approach is to follow the successful Systematic Approach to tropical cyclone track prediction in that knowledge, procedures, and data bases for tropical cyclone formation and structure will be utilized. For the specific objective to assess numerical forecasts of tropical cyclone formation, the approach has been to objectively track and catalog analyzed and forecast low-level circulations plus relevant environmental parameters that may be related to the subsequent development or non-development of a tropical cyclone. Statistical analysis of the data base created through the catalog procedure will identify factors that are related to successful and unsuccessful dynamical model forecasts of tropical cyclone formation.

WORK COMPLETED

An automated and objective algorithm for detecting and tracking low-level circulations in numerical model analysis and forecast fields has been applied to the June-October 2001 period over the North Atlantic and western North Pacific Ocean basins for the Navy Operational Global Atmospheric Prediction System (NOGAPS). To identify the circulation and its associated physical characteristics, a bivariate normal probability distribution is used to fit an ellipse to the 850 hPa vorticity field. In addition to the basic characteristics of the circulation (i.e., size, shape, motion, amplitude), a set of

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14. ABSTRACT
The long-term goals are to create and deliver knowledge-based expert system modules that will allow the Joint Typhoon Warning Center (JTWC) forecasters to make more accurate and consistent forecasts of tropical cyclone formation and outer wind structure.

15. SUBJECT TERMS

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environmental parameters (Table 1) is defined relative to the 95% probability ellipse of the bivariate normal distribution fit to the vorticity field. Therefore, the potential for tropical cyclone formation can be assessed relative to the various environmental factors defined for developing and non-developing circulations.

Table 1
Model parameters defined for every analyzed and forecast circulation center that is identified and tracked.

Relative vorticity at 850 hPa (10^{-5} s^{-1})
sea-level pressure (hPa)
latent heat flux (surface) (W m^{-2})
shallow vertical wind shear (500-850 hPa) (m s^{-1})
deep vertical wind shear (200-850 hPa) (m s^{-1})
geopotential height thickness expressed as a difference from the surrounding region outside of the ellipse (1000-200 hPa) (gpm)
1000-500 hPa temperature difference expressed as a difference from the surrounding region outside the ellipse (K)
Vertical motion (Pa s^{-1})
Total precipitation (kg m^{-2})
Vapor pressure at 500 hPa (Pa)

RESULTS

Over the North Atlantic Ocean, the formation of low-level circulations that were tracked between 25 July- 31 October 2001 (Fig. 1) are stratified as to whether they first met the tracking criterion of $1*10^{-5}$ s^{-1} while over the western portion of North Africa or over water to the west of North Africa (Dorics 2002, Dorics et al. 2002).

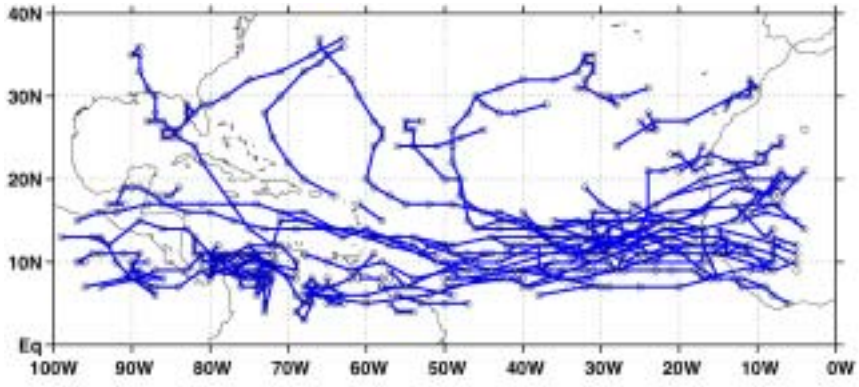

Figure 1.
Circulation tracks (12-h intervals) based on 850 hPa relative vorticity that were objectively identified and tracked between 25 July-31 October 2001.

The data base of analyzed and forecast circulation centers that existed for at least two days has been examined to determine the ability of NOGAPS to accurately predict the timing of the first appearance of the analyzed circulation center (Table 2). A forecast is considered early (late) if the first forecast of the circulation verifies before (after) the first analysis time. In the case of early forecasts, error statistics cannot be computed because the circulation has not yet appeared in the analysis. On-time forecasts occur when the first forecast of a circulation verifies at the first analysis time.

Table 2

Counts of forecasts that verify late, early, or on time with respect to the first analyzed occurrence of each circulation. Red values in parentheses reflect counts when the definition of On-Time is modified to include times that are with +/- 12 h of the first analysis time.

(Criterion Relaxed to +/- 12 h)	LATE	EARLY	ON-TIME	TOTAL	No Forecasts
First Analysis over Ocean	29 (14)	6 (1)	19 (30)	54	5
First Analysis over Land	18 (10)	31 (16)	36 (59)	85	0
TOTAL	47	37	55	139	5
			40% On-Time Forecasts		
TOTAL	(24)	(17)	(89)	(139)	

70% On-Time Forecasts

For all circulation, approximately 40% of the forecasts of circulations contained in NOGAPS forecast sequences that were initialized prior to the appearance of the analyzed circulation verified at the correct time. If the definition of on-time is relaxed to span the 12 h prior to and after the first analysis time, then 70% of the forecasts verified on time.

Also, forecasts of circulations that first appeared over the ocean tended to verify late while those that first appeared over land tended to be forecast to appear too early.

The distribution of forecast timing errors relative to forecast interval (Fig. 2) indicates that the majority of forecasts of formation over land that were too early were initiated more than 72 h prior to the first analysis time. Forecasts that were too late were typically closer to the first analysis time. For circulations that first appeared over water, the majority of forecasts were late with little relationship to the length of the forecast interval.

For western North Atlantic circulation systems, analysis of the various physical parameters associated with each forecast and verifying circulation indicate the quantities (e.g., sea-level pressure, size) were under-forecast during the early development period of a circulation. However, the errors became smaller as the circulation persisted and there is some indication of over-forecast errors for circulations that develop to at least tropical storm strength.

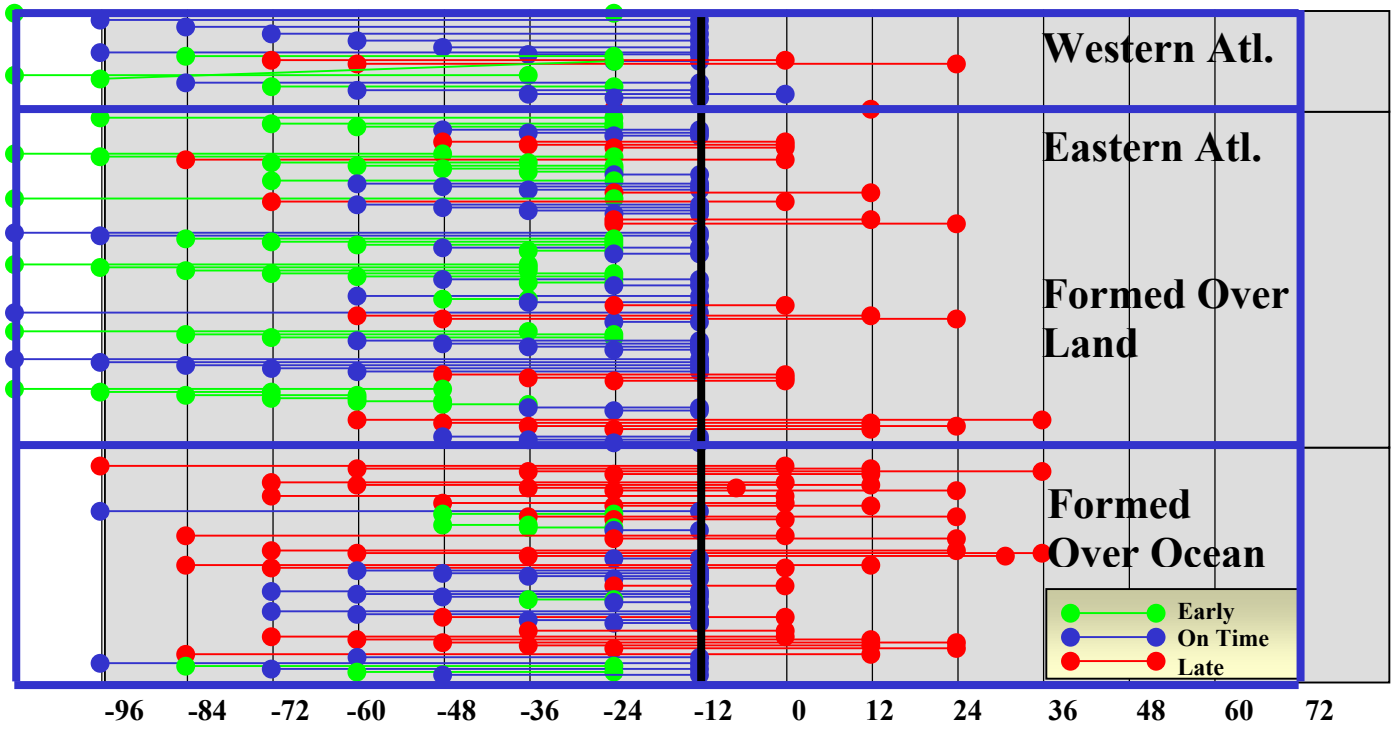

Figure 2.
Forecast history of the detection of vorticity centers over the western (top group) and eastern North Atlantic (bottom two groups). The time relative to the first analysis time (0) is given along the bottom. The start of each horizontal line marks when a forecast of the circulation was made. The end of each horizontal line indicated the time at which the circulation was forecast to appear. The length of the line denotes the forecast interval. For example, the top horizontal line indicates that 96 h prior to the first analyzed position a 84-h forecast was made that defined the formation to occur 12 h earlier than it actually did. This is an early forecast and is marked by the green line (see legend at lower right).

IMPACT/APPLICATIONS

Application of the new tracking algorithm to analyzed and forecast circulations will enable development of a knowledge-based data base that is objectively and automatically generated. The data base will form the basis of an expert-system module that will assist JTWC forecasters in evaluating circulations as their potential for developing into a tropical cyclone by placing the current forecast scenarios in the context of historical model traits.

TRANSITIONS

In this project, the application of the objective tracking procedure and generation of the knowledge-based data set will be transitioned to operations as part of a comprehensive system for assessment of potential tropical cyclone formation based on dynamical model forecasts and evaluation of other real-time products (i.e., satellite imagery linked to numerical model output).

RELATED PROJECTS

This project is related to the project titled Evolution of Tropical Cyclone Characteristics, in which the tracking algorithm has been developed. Further research concerning large-scale circulation variability and mesoscale characteristics of convective systems associated with developing circulations that is being conducted in the related project will be included in the generation of the expert system module for tropical cyclone formation and structure.

SUMMARY

A prototype data base that is meant to serve as the framework for an expert system module on tropical cyclone formation and structure as an aid to JTWC forecasters has been constructed. The data base contains factors that relate dynamical model fields to the synoptic-scale conditions that may impact model forecasts of tropical cyclone formation. Future development will augment the data base with estimates of mesoscale conditions related to convective systems associated with the developing circulations.

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Dorics, T., P. A. Harr, and R. L. Elsberry, 2002: Assessment of the potential for prediction of tropical cyclone formation in the Navy global model. *Preprints, 25th Conference on Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Boston, MA 02108, 222-223.

PUBLICATIONS

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